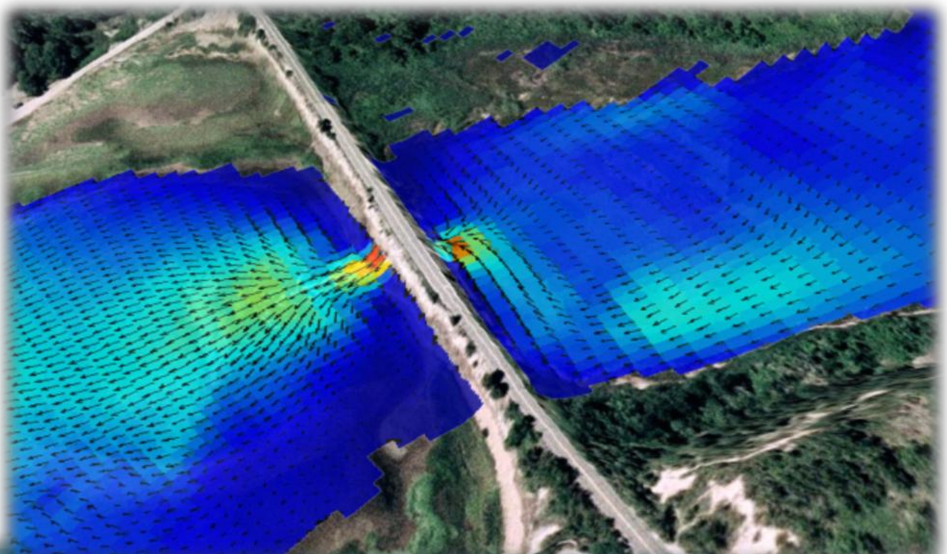
Herring River Restoration Project: Final Dike Control Structure Hydrodynamic Modeling



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1.0 INTRODUCTION

This report presents results from continued hydrodynamic modeling services related to the Herring River Restoration Project. The purpose of this analysis is to assess the response of the Herring River system for the detailed design of the newly proposed open span dike system. Specifically, this involves determining the response due to various tide gate and bay panel configurations to optimize both the adaptive management ability and cost of the proposed design.

The scope of work is geared towards simulating the preferred engineering dike design, layout, and adaptive management approach for the Chequessett Neck Road (CNR) dike, while also gaining valuable regional understanding of critical coastal hydrodynamics (sea level rise implications, tidal control structures influence, adaptive management, etc.) that could serve as a guide at other restoration sites. Originally, the scope of work included targeted simulations of the hydrodynamic components of three selected CNR alternatives, as well as explicit simulations of the final, preferred alternative dike plans developed to the 25% design stage. However, in the alternative scoping meeting (Task 1) with the Herring River Restoration Committee (HRRC), the approach was significantly modified to more comprehensively mesh with the overall adaptive management approach. This newly defined approach is geared to produce a more complete evaluation of potential tide gate types, configurations, and openings within the bridge / open span structure while better serving the adaptive management development in the future. This approach also is geared to make the design and construction of the new bridge structure more cost effective by reducing the total number of expensive tidal control gates that may be required. This new approach did not limit the number of alternative simulations (runs) and consists of the following components/steps:

1. Simulations to determine the number of tide gates and number of full panels needed
2. Width of individual tide gates and panels within the structure
3. Types of tide gates needed
4. Location/position of tide gates and panels in structure
5. Operations and adaptive management simulations to determine response to various opening combinations based on the final design recommendations developed in the previous steps. Model simulations for these scenarios include storm and sea level rise simulations in addition to the normal tidal conditions

Finally, this scope of work also provides simulations that demonstrate integration of adaptive management approach with restoration modeling and provide an improved understanding of tidal gate and flow control structure utilization in a large restoration project. Results of this suite of simulations can be used to help guide the adaptive management approach.

The previous modeling efforts (Woods Hole Group, 2012) evaluated the required openings sizes throughout the system to attain various benchmark water and restoration levels, which were a critical component of the conceptual designs and the environmental impact assessment. The opening sizes were assumed to be fitted with slide-type gates spanning the entire opening width. For example, the 165 foot width opening at Chequessett Neck Road, which produces the optimal restoration scenario, was simulated with up to 27 gate structures that could be managed to advance the restoration in a phased, step-wise approach.

Currently, as the restoration project advances into the design stages, the need for the configuration, type, and quantity of flow control structures integrated into the proposed open span dike is required. Woods Hole Group determined that the number of gates could be reduced such that they would not be required across the entire width of the new opening while still providing the operational flexibility required to implement an adaptive management approach. Control structures need to be able to control tides, water levels and salinity levels upstream of the dike through incremental openings. However, these control structures are costly. Approaching $200,000 per unit, total cost for just this hardware delivered could be $4,000,000-5,000,000 if structures were to span the entire length of the proposed open span structure. As a result, this scope of work is primarily geared around minimizing costs while still providing desired operational control is important.

For example, an example of results from the previous modeling effort (Woods Hole Group, 2012) are shown in Figure 1 and demonstrate the technical basis for reducing tidal control devices across the entire 165’ opening. Figure 1 shows the water surface elevation (vertical axis) of Mean High Water Spring (MHWS) in the Lower Herring River Basin as a function of effective opening size at Chequessett Neck Dike (horizontal axis). These results are taken from the Woods Hole Group (2012) hydrodynamic model with a 165’ width dike and varying vertical slide gate openings. The three black diamonds on the curve show the MHWS water elevation for existing conditions, and two of the end point restoration alternatives (3’ and 10’ sluice openings across the entire 165’ width). The results show that a significant portion of the high water change in water surface elevation within the system occurs for only a small portion of the opening size. For example, between effective dike openings of 10 to 250 ft^2, approximately 85% of the total increase in water surface elevation occurs (compared to the target goal of 165’ wide by 10’ high opening). As such, even small openings at the start of the restoration project will result in significant changes to the ecology, processes, and impacts within the system. However, after a certain point in the restoration process, larger openings will results in less significant changes in water surface elevation, and smaller influence throughout the system.

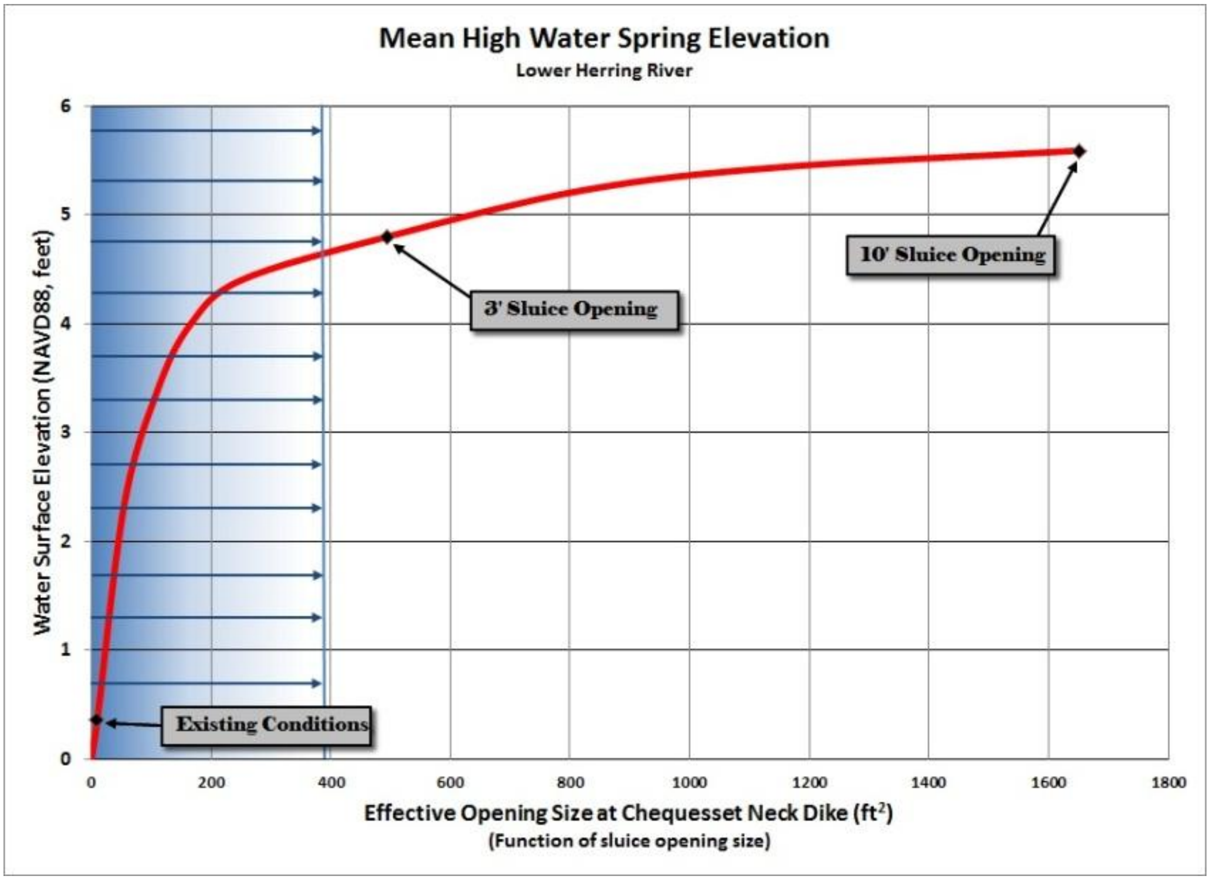

Figure 1. **Mean High Water Spring water surface elevation in Lower Herring River as a function of effective opening size at Chequessett Neck Dike.**

Therefore, as an example application for the dike design, the blue area on Figure 1 illustrates a zone of water elevations that could be controlled with a reduced number of gates. The zone indicates that to get nearly 90% of the tide increase (and as a proxy, 90% of the restoration), that a smaller portion of the effective area may adequately provide control over these initial stages of the adaptive dike opening(s). As the restoration advances, and the significant changes to the system have been realized, additional openings for the later stages of the restoration could be managed through larger incremental openings (that result in smaller changes in water surface elevation). For example, a 400 ft^2 effective opening after the 3' sluice opening target is attained produces only 6 inches in water surface elevation increase. Therefore, the remaining area may be able to be treated as simple opened or closed regions bays by using concrete panels that could be removed when ready to allow more tidal exchange. In other words, instead of having 25 or more tidal control devices spanning the entire 165' opening, limited tidal control mechanisms would be needed to produce the same managed restoration ability, while still providing the ability to add more tidal control devices if necessary. This approach significantly reduces capital and maintenance cost, reduces the number of complex moving parts, and provides modular ability to modify the dike into the future to meet changing or unexpected needs.

While reducing the number of tidal control structures in the dike system is an important consideration to the overall cost, the ability to control more than just the high water level in the estuary was also considered in the evaluation of the tidal control structure reduction. The ability to control the mean water level, the tidal range, and the low water level were also considered when evaluating the tidal control structure configuration. For example, in the adaptive restoration approach, it may be desirable to drain the system to a lower level to arrest sediment in certain points with the system, or hold water in the system for a portion of the tidal cycle to encourage sediment deposition. These considerations were also given weight when considering the potential tidal control structure configuration.

Ultimately, the hydrodynamic model was implemented to (1) provide detailed design requirements for the tidal control structures within the proposed bridge/dike system; (2) ensure that the proposed tidal control structure and operational strategy provide the required tidal control flexibility, while minimizing costs and complexity; (3) inform the development of an adaptive approach to achieve restored tidal conditions with minimal risk to property and the environment, and (4) provide flexibility for a range of physical conditions (storm surge, precipitation events), including projected sea level rise.

2.0 TIDAL CONTROL STUCTURE SIMULATIONS

The tidal control structure simulations presented in this chapter were focused on identifying the conceptual level design for the tide gates to be fitted in the proposed open span dike structure at Chequessett Neck Road (CNR). This required developing simulations that determined:

- The ***type*** of tidal control structures (gates and panels) needed to provide the operational flexibility required to implement an adaptive management approach

- The ***number*** of tidal control structures (gates and panels) needed to provide the operational flexibility required to implement an adaptive management approach

- The ***location*** of the tidal controls structures (gates and panels) within the dike system

- The ***size*** of the individual tidal controls structures (gates and panels) within the dike system

As part of this design process, various gate structures and openings in the open span bridge design were evaluated in order to provide the highest level of tidal control for the adaptive restoration approach. The goal of the modeling process was to determine the tidal control structure design configuration that provided the ability to maximize the control of the tides ebbing and flooding into the system. The modeling defined the upper and lower bounds of various key physical parameters to develop a design such that any desired water level and salinity level combination could be obtained in the adaptive management process, while minimizing the number (and thus cost) of required tidal gates. The following sections provide information regarding the steps in the modeling process that were used to determine the required tidal control structures by identifying the maximum and minimum extents of feasibly attainable water levels, especially in the early stages of the restoration program.

2.1 IMPACTS OF FULL PANELS

The first step in reducing the number required tidal gates was to determining the impact of including full pre-cast concrete panels in the place of slide gates assumed in the first round of modeling. These concrete panels would basically create openings in the dike structure that would be binary in behavior (i.e., either open or closed) over there associated width.

Figure 2 presents results from Herring River model simulations used to determine the number of slide gate structures (and subsequently the number of full height panels) required to adaptively manage the response within the Herring River system. The vertical axis in Figure 2 presents the water surface elevation (in feet, NAVD88), while the horizontal axis presents the effective opening size at the CNR bridge structure. This effective opening size is a function of slide opening and/or panel removals.

The green line shows the expected elevation of Mean High Water (MHW) (as opposed to Mean High Water Spring [MHWS] presented in Figure 1) in the Lower Herring River Basin as the opening at CNR becomes larger. This green line was produced from a series of model runs that consisted of slide gates that spanned the entire width of the CNR opening (165 feet). The slide gates were slowly opened (primarily uniformly) across the entire width of the opening to allow increased tidal exchange. For example, a uniform 3' sluice (slide) opening across the 165 foot width of the bridge produces a MHW elevation of approximately 4.0 feet, as indicated by the black diamond on the green curve. The red broken line also shows the expected MHW in the Lower Herring River Basin as the opening at CNR becomes larger. However, for this set of simulations, the opening size was increased by complete opening of a slide gate or removal of an entire panel. This created incremental 6' wide by 10' high openings that would be represented by either a complete panel removal or a full slide gate opening. As such, if only panels were used, the water surface elevation response with the Herring River would progress ("jump") between the black squares on the curve. This would result in loss of the ability to control the water surface elevation. Therefore, the correct mix of slide gates and panels is a critical balance of adaptive management control and appropriate cost and maintenance savings.

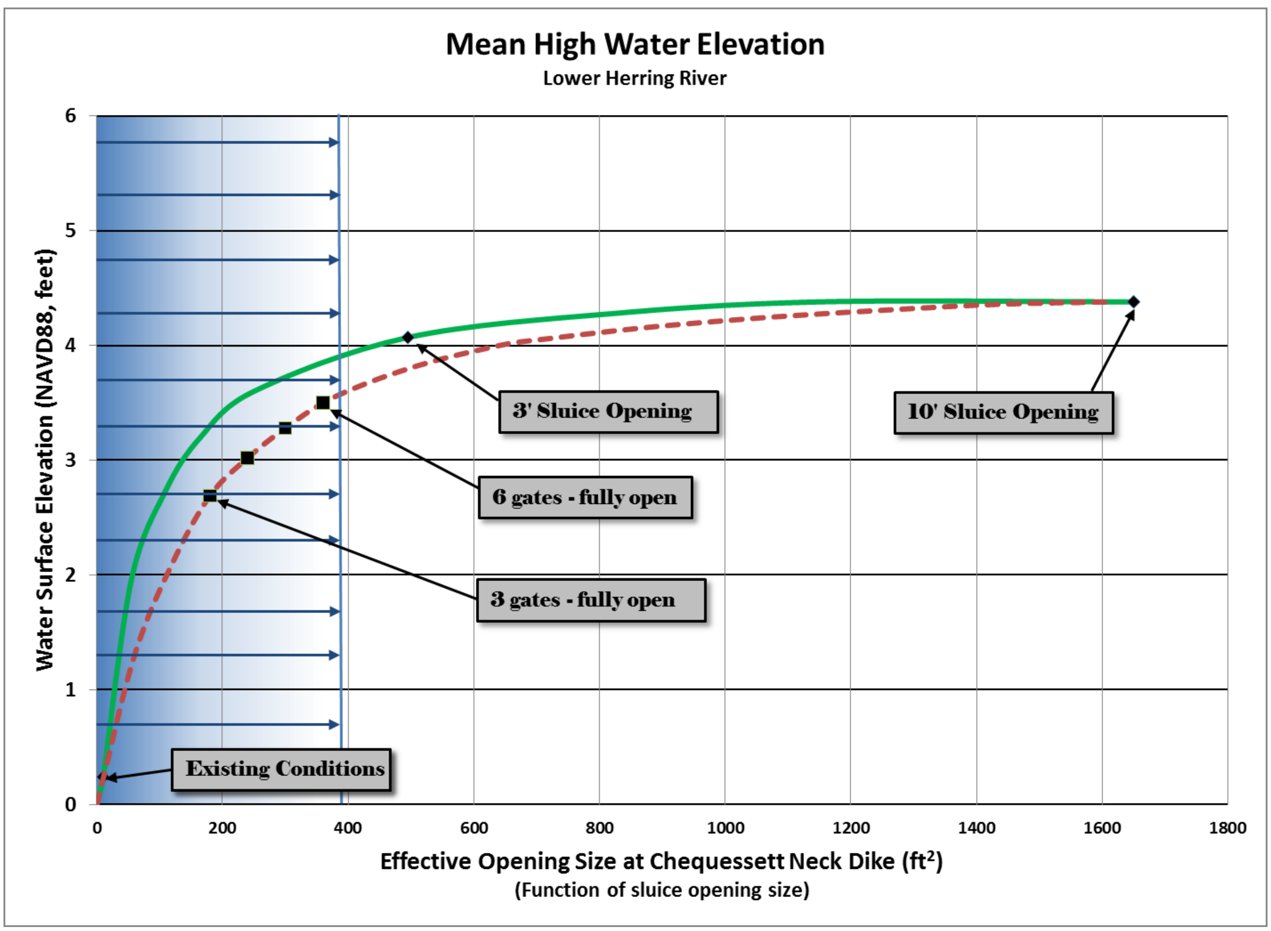

Figure 2. **Herring River model results illustrating the level of Mean High Water expected within the Lower Herring River sub-basin as a function of effective opening size.**

The results are used to determine the appropriate number of slide gates needed within the new open span structure crossing Chequesset Neck Road.

Figure 2 also illustrates the limitation of using effective opening size as a scale for the opening size in the dike structure. For example, a 180 square foot opening corresponds to three 6-foot wide slide gates open all the way to the upper ceiling of the culvert (10 feet high) or 3 complete panel removals. A 180 square foot opening also corresponds to six 6-foot wide slide gates open 5 feet. Although the effective cross sectional area is the same for both these cases, the flow conditions and tidal exchange is significantly different since the cross-sectional area exposed to the water level changes as a function of time. As such, the cross-sectional area itself varies with the changing tide level. For example, the six 6-foot wide slide gates open 5 feet scenario has a greater area available for tidal flow during the lower portion of the tidal cycle than the three 6-foot wide slide gates open ten feet. This phenomenon explains the difference between the green line and the broken red line in Figure 2 and also indicates that care must be taken when evaluating results solely using an effective opening size. The time-varying nature of the cross-sectional area available to flow is also an important factor when considering impacts to other tidal benchmarks, as will be discussed in the following section.

This first round of structural simulations only evaluated in the impact of panels on the high water levels (MHW, MHWS, etc.) within the system. Based on this analysis, which focused on the impact of using panels in the place of gates within the structure, the following conclusions can be determined:

- As shown in Figure 1 and 2, previous modeling simulations indicated that once Mean High Water exceeds approximately 4.0 feet NAVD88 (Figure 2), or Mean High Water Spring exceeds approximately 4.7 feet NAVD88 (Figure 1), the opening of additional area in the tidal control structure has a more limited impact on the water levels in the system. In other words, larger jumps in the size of the opening (e.g., removing an entire pre-cast concrete 8’x10’ panel) do not significantly impact changes in the water levels within the system. Therefore, a finer level of tidal control is required in the early stages of the restoration (prior to MHW levels in the system exceeding 4 feet NAVD88). As such, slide gates are needed to allow for better control of the water levels in these early stages. Based on the analysis in this section (2.1), at minimum eight (8) slide gates would be required. This is a reduction from the original simulations and design approach that would have required up to 27 slide gates spanning the entire 165 foot width of the CNR bridge. Additional slide gates (beyond 8) do not add significant control to the high water level in the system, indicating those areas in the dike system could be installed with full pre-cast concrete panels.

- The size of both the panels and gates has been determined based on (1) the standard sizes of tide gates, (2) the water forces expected to impact the full panels, (3) the results of the modeling for various size openings, and (4) maintaining manageable panel sizes that could adequately be removed/replaced. As such, the tidal slide gates are recommended to be 6’ wide by 10’ tall, while the panels could be 6-8’ wide and 10’ tall.

2.2 THE IMPACT OF MINIMIZATION OF TIDE GATES

The first round of tidal control structure simulations (section 2.1) focused on the reduction of the number of tide gates by replacing them with panels in order to determine the number of potential tide gates required. Those simulations (section 2.1) evaluated full gate openings such that the 6 foot wide area in the dike was either fully open or fully closed. However, in reality, there are an infinite number of combinations of openings when partial opening a number of slide gates. Therefore, simulations were conducted that varied the opening heights and gate combinations to evaluate water level responses within the Herring River system during the early stages of the restoration process (opening sizes less than 400 square feet). This set of simulations was geared towards ensuring the 8 tide gates identified in Section 2.1 could adequately provide a full range of water levels (e.g., MHW and MLW) and tidal range that may be desired during the adaptive management stages. As such, this set of simulations was geared towards ensuring the eight slide gates identified in Section 2.1 could also provide full tidal control of the MLW level and tidal range.

Figure 3 presents results from a wide variety of slide gate and panel openings and shows the water level responses in the Lower Herring River Basin. The blue line presents the resultant MHW levels, while the red line presents the MLW levels. In many cases, openings with similar effective cross-sectional areas were tested to determine the impact on the tidal benchmarks upstream of the proposed dike. For example, there were two scenarios with a 72 square foot opening: (1) six gates each open a total of 2 feet, and (2) 2 gates each open a total of 6 feet. Although the total cross-sectional area was the same, due to the time-varying nature of the portion of the area that is actually conveying water, these two scenarios produce vastly different results specifically when considering the low water levels that are produced. The six gates open each 2 feet are able to drain a greater amount of water (MLW is approximately -2.0 feet NAVD88) than 2 gates open a total of 6 feet (MLW is approximately 0.2 feet NAVD88). However, the MHW level produced by the two scenarios is approximately the same (within 0.1 feet).

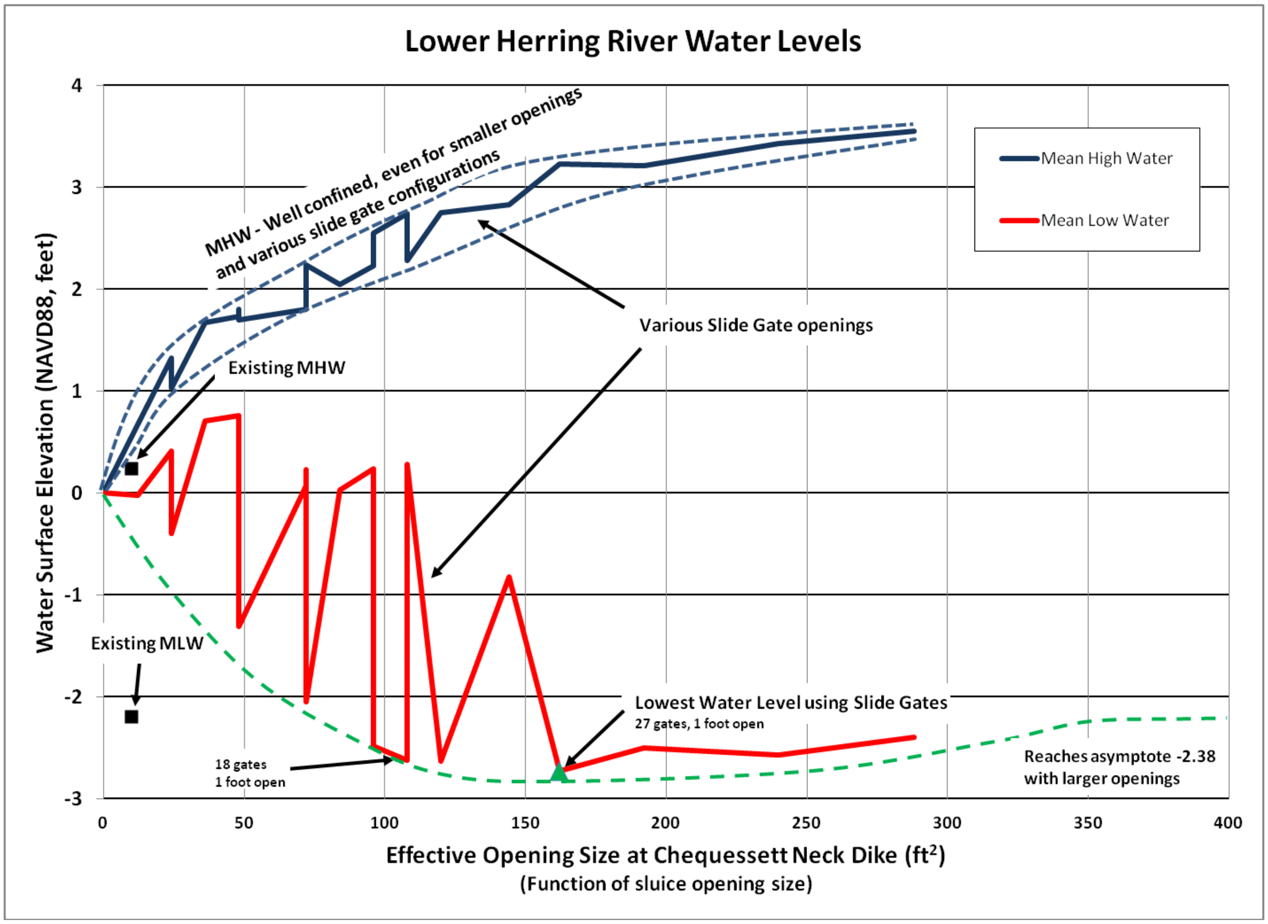

Figure 3. **Herring River model results illustrating the level of Mean High Water and Mean Low Water expected within the Lower Herring River sub-basin for a wide variety of slide gate openings.**

In fact, MHW remains well confined throughout the various scenarios indicating that 8 slide gates can provide adequate control of the high water levels in the system for smaller openings at the dike. Mean low water; however, fluctuates significantly for the various slide scenarios and the slide gates alone are not capable of draining enough water from the system to significantly lower the mean low water in the system. For example, the lowest MLW level can be in the system using just slide gates is approximately -2.7 feet NAVD88 for a case with a 1 foot opening across the entire width of the dike. This is approximately only half a foot lower than the existing MLW in the system. While the variations in the low water indicate that there is an ability to control the tidal range in the system by using various slide gate opening combinations, the slide gates also limit the minimum water levels that can be attained in the system. Using solely slide gates and panel openings, the amount of water that can be drained from the system is limited since the slide gate openings also increases the amount of water transported into the system (resulting in more water to drain).

As part of the adaptive management approach, it is envisioned that there may be cases where the low water in the system is desired to be lower than what is attainable using slide gates alone. As such, additional simulations were conducted to determine the potential influence of using combination slide/flap gates in concert with the slide gates and panels to enhance the ability to control the low water levels in the system through non-linear tidal exchange.

2.3 INCLUSION OF COMBINATION SLIDE/FLAP GATES

In order to gain potentially more operational control on the water levels, and specifically the tidal range and low water levels, another set of model simulations was conducted to determine the influence of combination slide/flap gates on the water levels within the Herring River system. First, a brief assessment was performed to minimize the number of combination more costly combination slide/flap gates. A minimum number of two combination flap/slide gates were selected such that the new dike could replicate existing conditions at the current dike, which consist of a single slide gate and two flap gates.

Figure 4 shows time series model results for model simulations using 2 flap gates (red line), 3 flap gates (blue line), and 4 flap gates (green line) and also include a single slide gate open 1 foot. Results are presented for water surface elevation results in the Lower Herring River basin. As expected, the low water elevation at low tide is lower for cases with more flap gates. However, the relative difference between the flap gate results in successive tides diminishes. For example, Figure 4 shows that the difference in the low water elevation for 2 flap gates versus 3 flap gates was approximately 0.2 feet at the first low tide in the simulation, but that difference was reduced to 0.1 feet on the next low tide. Eventually, and relatively quickly, these two time series converge during low tides, such that 2 flap gates produce the same low tide water level as 4 flap gates. As such, two combination flap gates were recommended for added control of the tide range and low water levels within the system.

Subsequently, a number of simulations were conducted using 2 combination flap/slide gates in concert with 6 slide gates. Figure 5 presents a subset of these results and indicates the ability to attain lower mean low water levels by appropriate utilization of the flap gates. The blue bars in Figure 5 show the tidal range that can be attained for a range of scenarios with the 2 combination flap/slide gates. Scenarios include a variety of side gate opening combinations (heights and number of open gates). Not only can lower mean low water levels be reached than when using slide gates alone, but also the ability to control the tidal range and the mean water level in the Herring River system is also enhanced. Additionally, low water can be reduced even further than indicate by closing all slide gates and only allowing flow out of the Herring River system through the combinations gates.

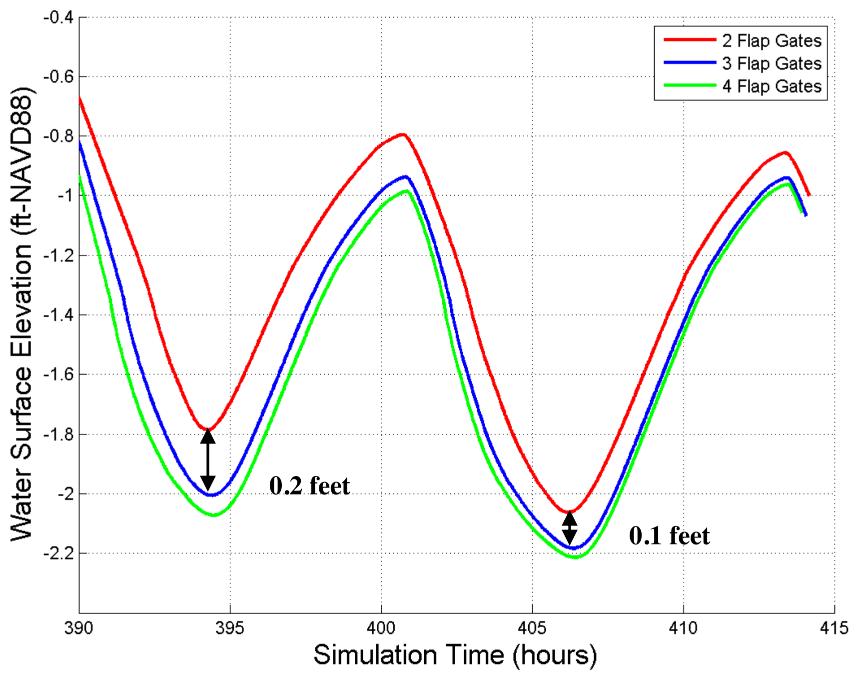

Figure 4. **Herring River model results illustrating the influence of flap gates on the low water tide levels in the Lower Herring River sub-basin using 2 flaps (red line), 3 flaps (blue line), or 4 flaps (green line).**

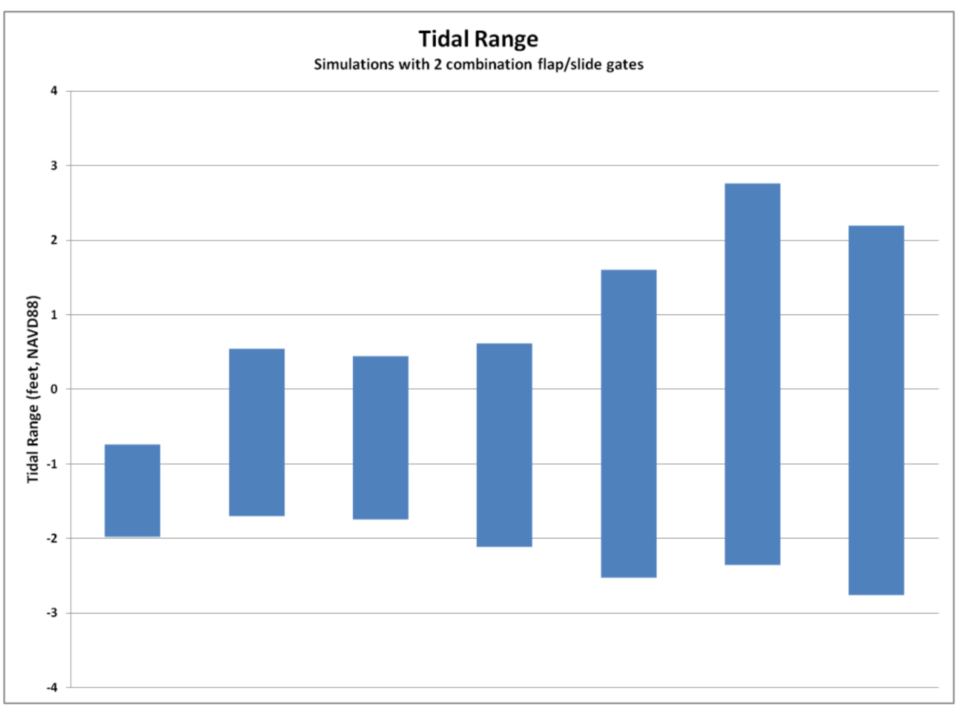

Figure 5. **Illustration of tidal range for a number of model scenarios using 2 combination flap/slide gates.**

Overall, the results of the model simulations using two combination slide/flap gates include:

- Utilizing combination flap/slide gates provides non-linear control of tidal exchange and therefore allows for improved operational control of mean tide level and the tidal range

- A minimum of two combination slide/flap gates were selected to replicate existing conditions

- Inclusion of combination flap/slide gates provides the ability to lower MLW in situations where it may be needed or desired. Combination gates can also be shut if necessary to eliminate all tidal exchange, or just allow flow out of the system

- Expect that actual observed water levels may vary from model results based on the type of combination slide/flap gate selected. The elevation head difference required to open individual flap gates is likely dependent on the type of combination gate used and was assumed in the model.

2.4 DIKE CONTROL STRUCTURE CONCEPTUAL DESIGN

Based on the results of the simulations described above, a conceptual design layout of the tidal control structures within the proposed box beam bridge dike system is presented in Figure 6. This conceptual design includes:

- A total opening of 165 feet with all panels removed and all slide and combination gates open. The opening consists of a 66' center section and two 49.5 feet sections on either side of the center section. There are 3' wide piles/abutments that separate the sections containing the tidal control components.

- A total of 2 combination slide/flap gates (shown by the green areas in Figure 6). The combination gates are 6 feet wide and 10 feet in height. They are positioned in the center span.

- A total of 7 slide gates (shown by the yellow areas in Figure 6). The slide gates are also 6 feet wide and 10 feet in height. Three of these gates are positioned in the center section, while two gates each are contained in each of the edge sections. Although only 6 gates are required, a seventh gate was added for redundancy and in case of operation failure of one of the other primary gates. This additional gate would also allow for maintenance requirements on damaged or compromised gate structures.

- A total of 16 pre-cast concrete removable panels. Some of the panels are 6 feet wide, while others are 8 feet wide. There are 6 panels in the center section and 5 panels in each of the edge sections.

This proposed configuration was developed by identifying the maximum and minimum water level attainable within the Herring River system given the forcing tidal levels in Wellfleet Harbor using tidal control. As such, any feasible water level combination (MHW, MLW, tidal range. MTL) should be attainable using the proposed design configuration. The relatively complex development procedure documented above was necessary to define the maximum and minimum physical bounds and was geared to allow for full operational control of the system.

In summary,

- A maximum number of 8 slide gates are required to accurately control the water level prior to being able to remove full pre-cast concrete panels. More gates could be used; however, additional gates do not add any significant operational control.

- Two of the recommended 8 slide gates should be combination slide/flap gates to provide increased control of the low water, mean tide level, and tidal range within the Herring River system. The combination gates, specifically the gate component allowing for additional flow out of the system, provide the ability for non-linear exchange of water flux. Therefore, the flap components provide ability to shift the mean tide level and allow for increased drainage capacity if desired.

- An additional slide gate (9^{th} gate) was added to the dike system for redundancy, in case of a gate failure or required maintenance on the primary gate(s).

- The sixteen (16) pre-cast concrete panels are intended to be operated in the later stages of the restoration program (following attaining mean high water levels over approximately 4.0 feet NAVD88). At these later stages of the restoration design, concrete panels can be fully removed and have a less significant impact on the water levels within the system.

In addition, the proposed configuration presented in Figure 6 represents one possible configuration of the tidal control structures within the proposed dike structure. Although, Woods Hole Group recommends that the number of slide, combination, and panels remain the same for any configuration, the positions of the gates can be modified to create alternative physical layouts. For example, if the was a desire for a larger contiguous opening, the outer slide gates could be moved adjacent to each other to create a larger pre-cast concrete opening in future stages of the restoration process. However, at the same time, significant deviations from the proposed layout in Figure 6 should be avoided. For example, the combination gates should be located in the center section, which is expected to align with the Herring River channel thalweg.

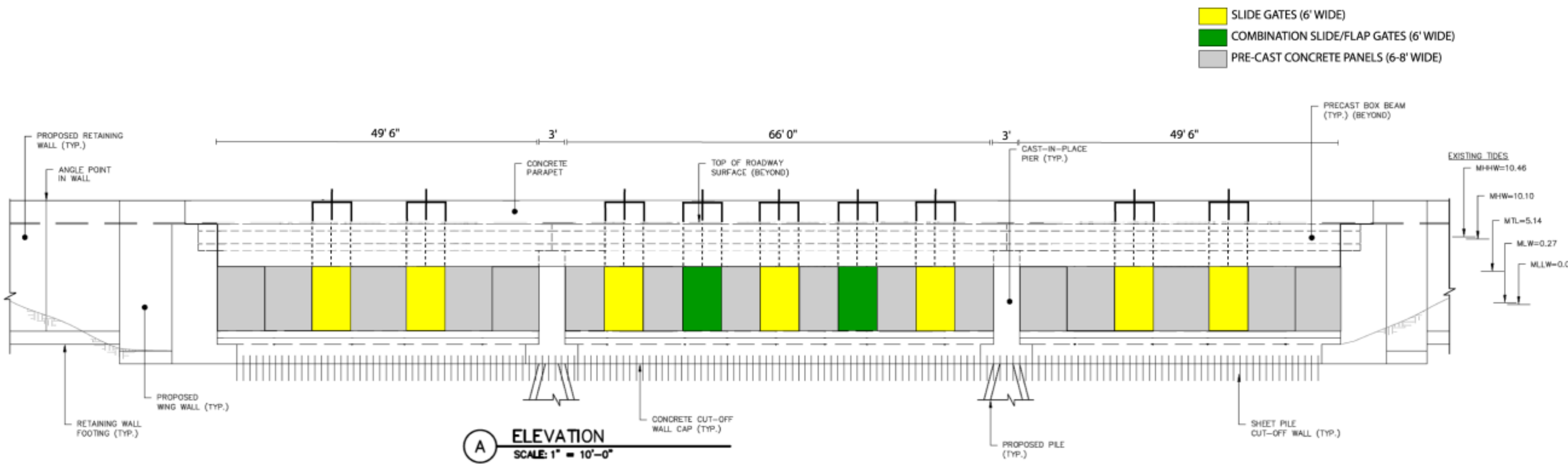

Figure 6. **Conceptual box beam bridge layout with tidal control structures. Yellow areas represent slide gates (6 feet wide), green areas represent combination flap/slide gates (6 feet wide), and gray areas indicate pre-cast concrete panels (6 to 8 feeet wide).**

2.5 ADAPTIVE MANAGEMENT SIMULATIONS

Using the conceptual layout presented in Figure 6, a number of model simulations were conducted to provide adaptive management scenarios and targets and were focused on smaller openings that were expected to be utilized in the early stages of the restoration program (e.g., prior to a MHW level of approximately 4.0 feet NAVD88). In these earlier stages, the restoration process will rely on the slide and combination gates and not the pre-cast concrete panels, although a full open slide gate can be substituted by a concrete panel removal if desired. These simulations included normal tidal conditions, storm events (storm surge) and sea level rise cases. Results from these simulations were post-processed to produce standardized output information in the same format as results from previous modeling scenarios (Woods Hole Group, 2012) and added to the database of adaptive management simulations conducted for the Herring River system. The full standardized output results will be provided to the Herring River Restoration Committee for their planning purposes and for use in the adaptive management program.

Even with the reduction of the required number of slide gates, there are still an infinite number of combination openings that could be prescribed for the recommended design layout. While the recommended design allows for full operation control of water levels between a MHW level of approximately 4.0 feet NAVD 88 (MHWS level of approximately 4.7 feet NAVD88) and a low water approximately equivalent to invert of the seafloor downstream of the Herring River (excluding freshwater discharge), various openings were simulated to provide restoration targets at these early stages. As such, the results presented in this section provide examples of the restoration water levels and salinities that can be obtained given various openings using the gates only. Additional cases can be simulated to further refine the potential results; however, results for additional opening simulations will fall within the range of the results presented herein. Results associated with full panel removals have been determined in earlier model simulations, and are generally less critical since they produce less significant variations in the physical results. Table 1 provides a summary of the various simulations conducted, which provide a reasonable cross-section of expected adaptive management scenarios using the tidal gates in the recommended design. All scenarios assume that the two combination gates are fully closed and operating in flap mode.

Table 1. Simulated gate openings for the recommended design. Simulations were conducted for scenarios indicated by the "X".

Model Simulations		Number of slide gates open						
		1	2	3	4	5	6	7
Opening Height (feet)	1	X	X		X			X
	2	X	X			X	X	
	4							
	6		X		X	X	X	
	8	X			X			
	10			X				X

Table 2 and 3 present the mean high water and mean low water results, respectively, from the simulations presented in Table 1 for the Lower Herring River basin. Tables 4 and 5 present the mean high water and mean low water results, respectively, from the simulations presented in Table 1 for the Mill Creek basin.

Table 2. Mean High Water (in feet NAVD88) results for the simulated gate openings presented in Table 1 in the Lower Herring River basin.

Model Simulations		Number of slide gates open						
		1	2	3	4	5	6	7
Opening Height (feet)	1	-0.96	-0.27		0.60			1.43
	2	-0.27	0.59			1.95	2.19	
	4							
	6		1.81		2.76	3.03	3.23	
	8	0.37			2.94			
	10			2.51				3.63

Table 3. Mean Low Water (in feet NAVD88) results for the simulated gate openings presented in Table 1 in the Lower Herring River basin.

Model Simulations		Number of slide gates open						
		1	2	3	4	5	6	7
Opening Height (feet)	1	-2.87	-2.71		-2.68			-2.75
	2	-2.56	-2.52			-2.75	-2.78	
	4							
	6		-1.88		-2.46	-2.61	-2.69	
	8	-2.08			-2.40			
	10			-2.16				-2.60

Table 4. Mean High Water (in feet NAVD88) results for the simulated gate openings presented in Table 1 in the Mill Creek basin.

Model Simulations		Number of slide gates open						
		1	2	3	4	5	6	7
Opening Height (feet)	1	-1.22	-0.66		0.15			1.07
	2	-0.66	0.15			1.63	1.93	
	4							
	6		1.46		2.52	2.82	3.04	
	8	-0.10			2.71			
	10			2.24				3.44

Table 5. Mean Low Water (in feet NAVD88) results for the simulated gate openings presented in Table 1 in the Mill Creek basin.

Model Simulations		Number of slide gates open						
		1	2	3	4	5	6	7
Opening Height (feet)	1	-1.33	-1.06		-0.75			-0.51
	2	-1.08	-0.75			-0.41	-0.36	
	4							
	6		-0.37		-0.26	-0.22	-0.20	
	8	-0.83			-0.22			
	10			-0.28				-0.15

Table 6 presents the results of mean salinity from the simulations presented in Table 1 for the Mill Creek basin. These tables represent some of the results from the various simulations. Full results (water levels, tidal benchmarks, and salinity) of all simulations (sea level rise, normal tides, storm events) were provided to the Herring River Restoration Committee for their planning purposes and for use in the adaptive management program.

Table 6. Mean salinity (in psu) results for the simulated gate openings presented in Table 1 in the Mill Creek basin.

Model Simulations		**Number of slide gates open**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
Opening Height (feet)	**1**	**9.2**	**11.6**		**12.2**			**13.6**
	2	**11.6**	**12.1**			**16.0**	**17.3**	
	4							
	6		**14.5**		**20.0**	**21.2**	**21.9**	
	8	**12.2**			**20.2**			
	10			**17.2**				**22.7**

3.0 REFERENCES

Woods Hole Group. 2012. Herring River Hydrodynamic Modeling Model Report. Prepared for the Town of Wellfleet and the Herring River Restoration Committee, prepared by Woods Hole Group Inc., 2012.